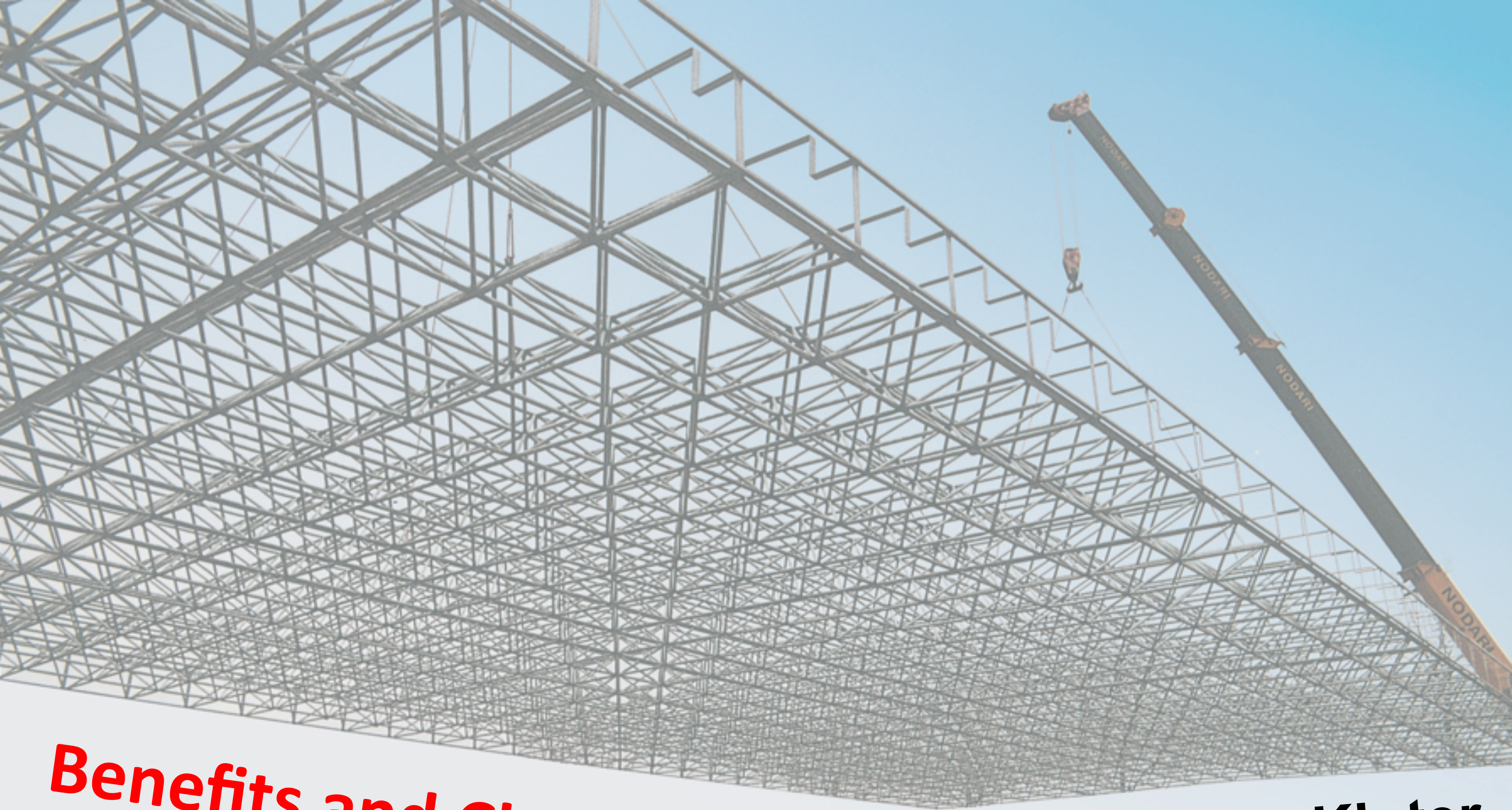


Benefits and Challenges of High Spatial Resolution in Climate Models

Jim Kinter

Center for Ocean-Land-Atmosphere Studies

George Mason University

Motivation

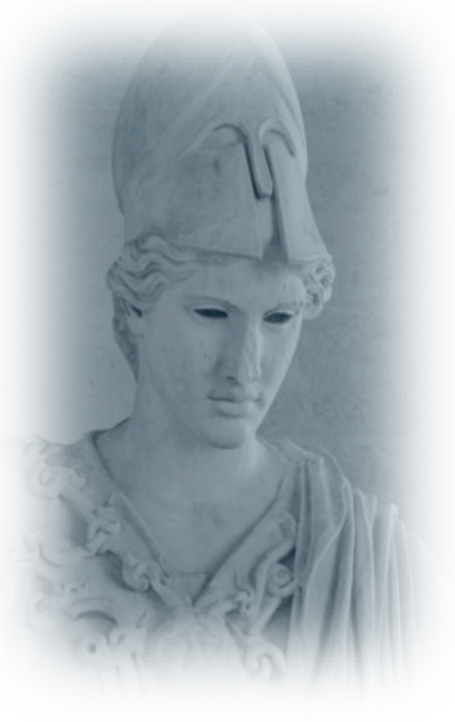
using global atmospheric models that are comparable to the atmospheric component of climate models →

- **Improving the fidelity of climate models** is difficult
- Numerical weather prediction has advanced by taking advantage of 10^6X increase in computing capability since 1980 through:
  - Increasing spatial resolution
  - Improving understanding of physical processes
  - Improving data assimilation methods
- Climate models have improved, primarily through the inclusion of more processes that are relevant to climate variability and change
- There is evidence that **enhanced spatial resolution** improves climate model fidelity (and may change our understanding of climate dynamics both qualitatively and quantitatively)

Origins of *Project Athena*

- 2008 World Modeling Summit: **dedicate petascale supercomputers to climate modeling**
- U.S. **National Science Foundation** **offered to dedicate the Athena supercomputer for 6 months** in 2009-2010 as a pilot study
- An **international collaboration** (***Project Athena***) was formed by groups in the U.S., Japan and the U.K. to use Athena to take up the challenge

Project Athena



Collaborating Groups

COLA - Center for Ocean-Land-Atmosphere Studies, USA (NSF-funded)

ECMWF - European Center for Medium-range Weather Forecasts, UK

JAMSTEC - Japan Agency for Marine-Earth Science and Technology, Research Institute for Global Change, Japan

University of Tokyo, Japan

NICS - National Institute for Computational Sciences, USA (NSF-funded)

Cray Inc.

Codes

NICAM:	Nonhydrostatic Icosahedral Atmospheric Model
IFS:	ECMWF Integrated Forecast System

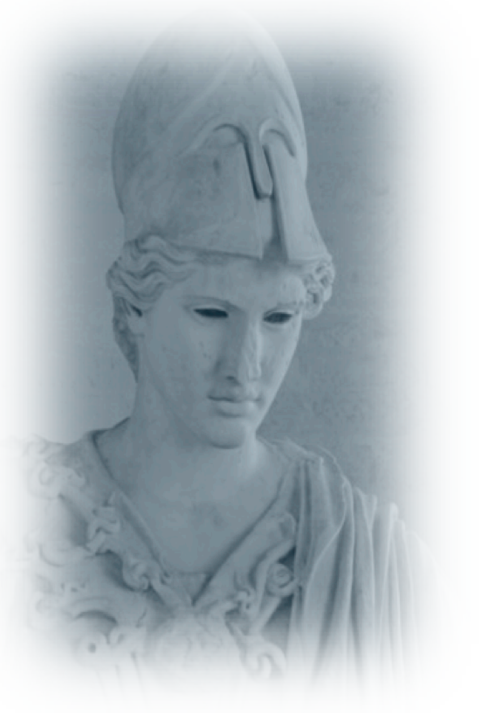
Project Athena Experiments

Model/Exp.	Resolution	# Cases	Period	Notes
NICAM / Hindcasts	7 km	8	103 days	21 May - 30 Aug 2001 - 2009
IFS / Hindcasts	125 km 39 km 16 km	48	395 days	1 Nov - 30 Nov (following year) 1960 - 2007
IFS / Hindcasts	10 km	20		1 Nov - 30 Nov (following year) 1989 - 2007
IFS / Hindcasts	125 km 39 km 16 km 10 km	9	103 days	21 May - 30 Aug 2001 - 2009 NICAM analogs
IFS / Summer Ensembles	39 km 16 km	6	132 days	21 May - 30 Sep selected years
IFS / Winter Ensembles	39 km 16 km	6	151 days	1 Nov - 31 Mar selected years
IFS / AMIP	39 km 16 km	1	47 years	1961 - 2007
IFS / Time Slice	39 km 16 km	1	47 years	2071 - 2117

http://wxmaps.org/athena/home/

Project Athena Publications

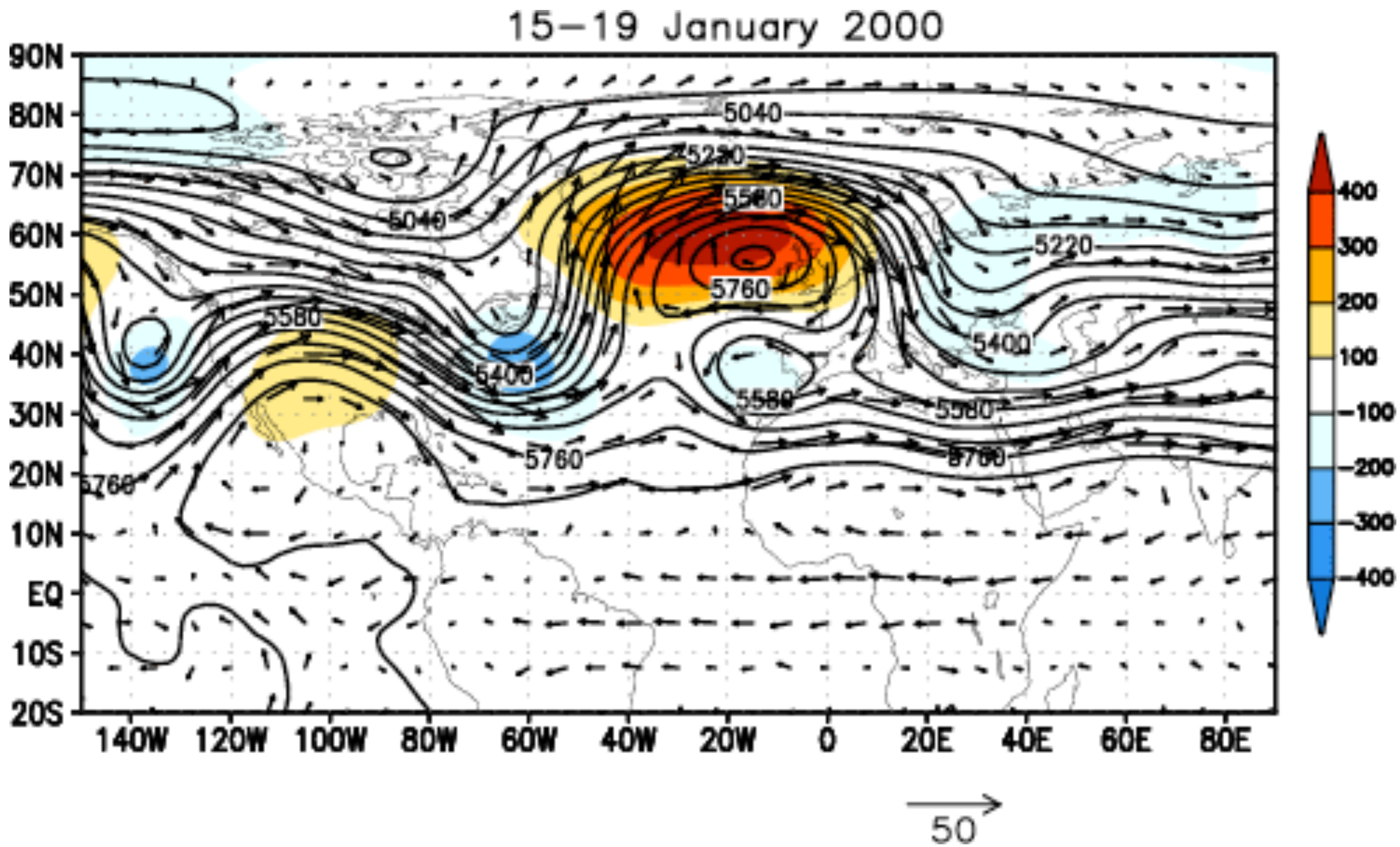
- Dawson, A., T. N. Palmer and S. Corti, 2012: **Simulating regime structures in weather and climate prediction models**. *Geophys. Res. Lett*., 39, doi:10.1029/2012GL053284 *
- Dirmeyer, P. A. and Co-Authors, 2012: **Evidence for enhanced land-atmosphere feedback in a warming climate**. *J. Hydrometeor.*, 13, 981-995.
- Dirmeyer, P. A. and Co-Authors, 2011: **Simulating the diurnal cycle of rainfall in global climate models: Resolution versus parameterization.** *Climate Dyn*. doi: 10.1007/s00382-011-1127-9.
- Jung, T. and Co-Authors, 2011: **High-Resolution Global Climate Simulations with the ECMWF Model in the Athena Project: Experimental Design, Model Climate and Seasonal Forecast Skill**. *J. Climate*, doi:10.1175/JCLI-D-11-00265.1. *
- Kinter III, J. L. and Co-Authors, 2013: **Revolutionizing Climate Modeling – Project Athena: A Multi-Institutional, International Collaboration**. *Bull. Amer. Meteor. Soc.,* 94(2), in press.
- Manganello, J. V. and Co-Authors, 2012: **Tropical Cyclone Climatology in a 10-km Global Atmospheric GCM: Toward Weather-Resolving Climate Modeling**. *J. Climate* 25, 3867-3893. *
- Miyamoto, Y., M. Satoh, H. Tomita, K. Oouchi, Y. Yamada; C. Kodama, J. L. Kinter III, 2013: **Gradient wind balance in tropical cyclones in high--resolution--global experiments**. *Mon. Wea. Rev*. (submitted).
- Palipane, E. and Co-Authors, 2013: **Improved Annular Mode Variability in a Global Atmospheric General Circulation Model with 16-km Resolution**. *J. Climate* (submitted).
- Satoh, M. and Co-Authors, 2011**: Intra-Seasonal Oscillation and its control of tropical cyclones simulated by high-resolution global atmospheric models**. *Climate Dyn*., doi10.1007/s00382-011-1235-6.
- Solomon, A. and Co-Authors, 2013: **The distribution of U.S. tornado risk in a changing climate**. *J. Climate* (submitted).



Sample Results

- **Large-scale atmospheric circulation variability**
- South Asian monsoon
- Resolution dependence of snow
- Diurnal cycle of precipitation
- Projection of climate change
- Tropical cyclones
- Tornadoes in climate simulation

Atmospheric Blocking



Geopotential height and vector wind on 500 hPa isobaric surface

Atmospheric Blocking

Tibaldi and Molteni (1990) index: At each longitude, compute:

$$ZGS = \left[\frac{Z(\phi_0) - Z(\phi_s)}{\phi_0 - \phi_s} \right]$$

$$ZGN = \left[\frac{Z(\phi_n) - Z(\phi_0)}{\phi_n - \phi_s} \right]$$

where Z = 5-day running mean geopotential height (m) at 500 hPa

Φ_n = 80°N+δ

Φ_0 = 60°N+δ

Φ_s = 40°N+δ

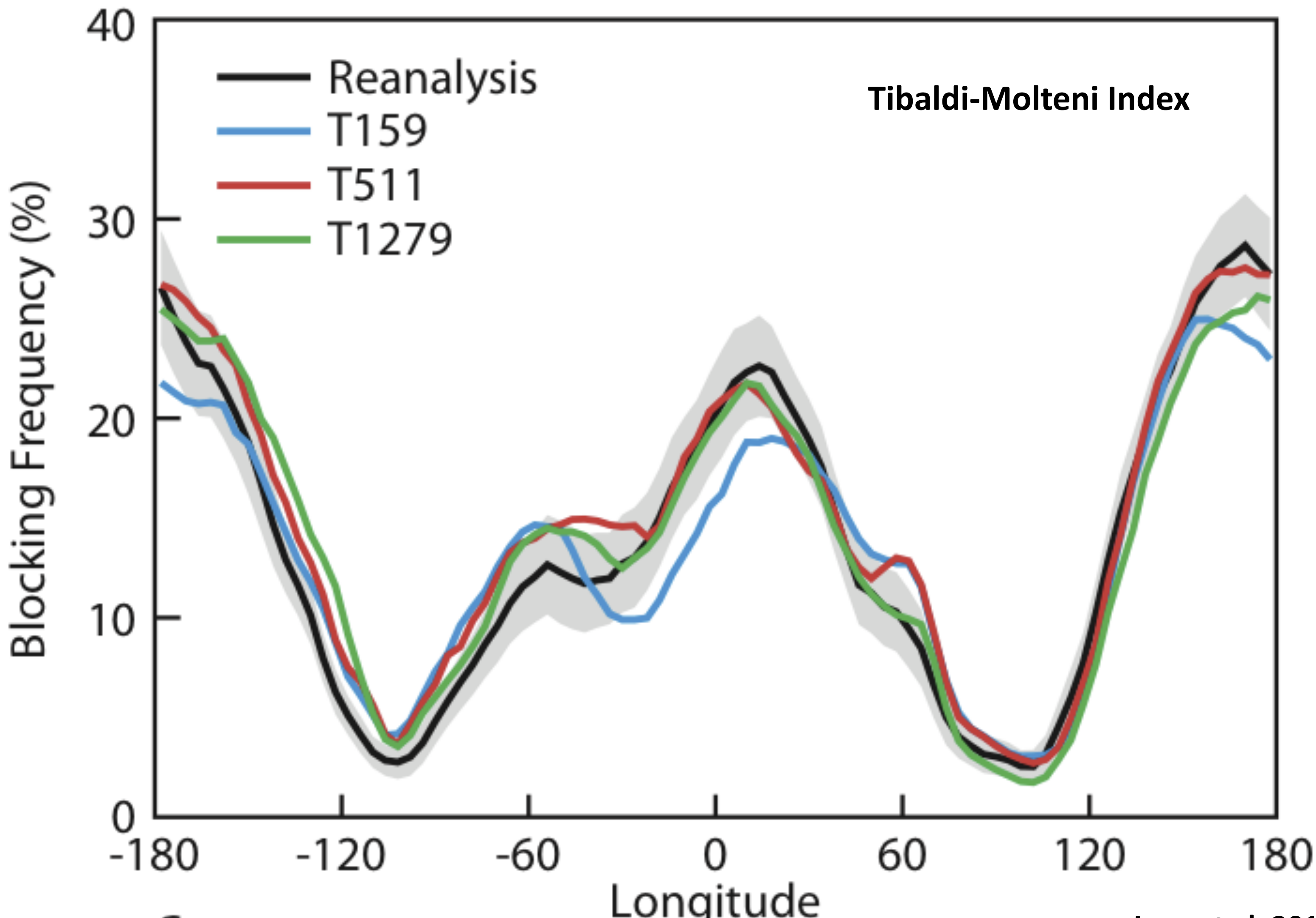
δ = -5°, 0°, or +5°

Blocking is occurring where, for at least one value of δ,

(1) ZGS > 0

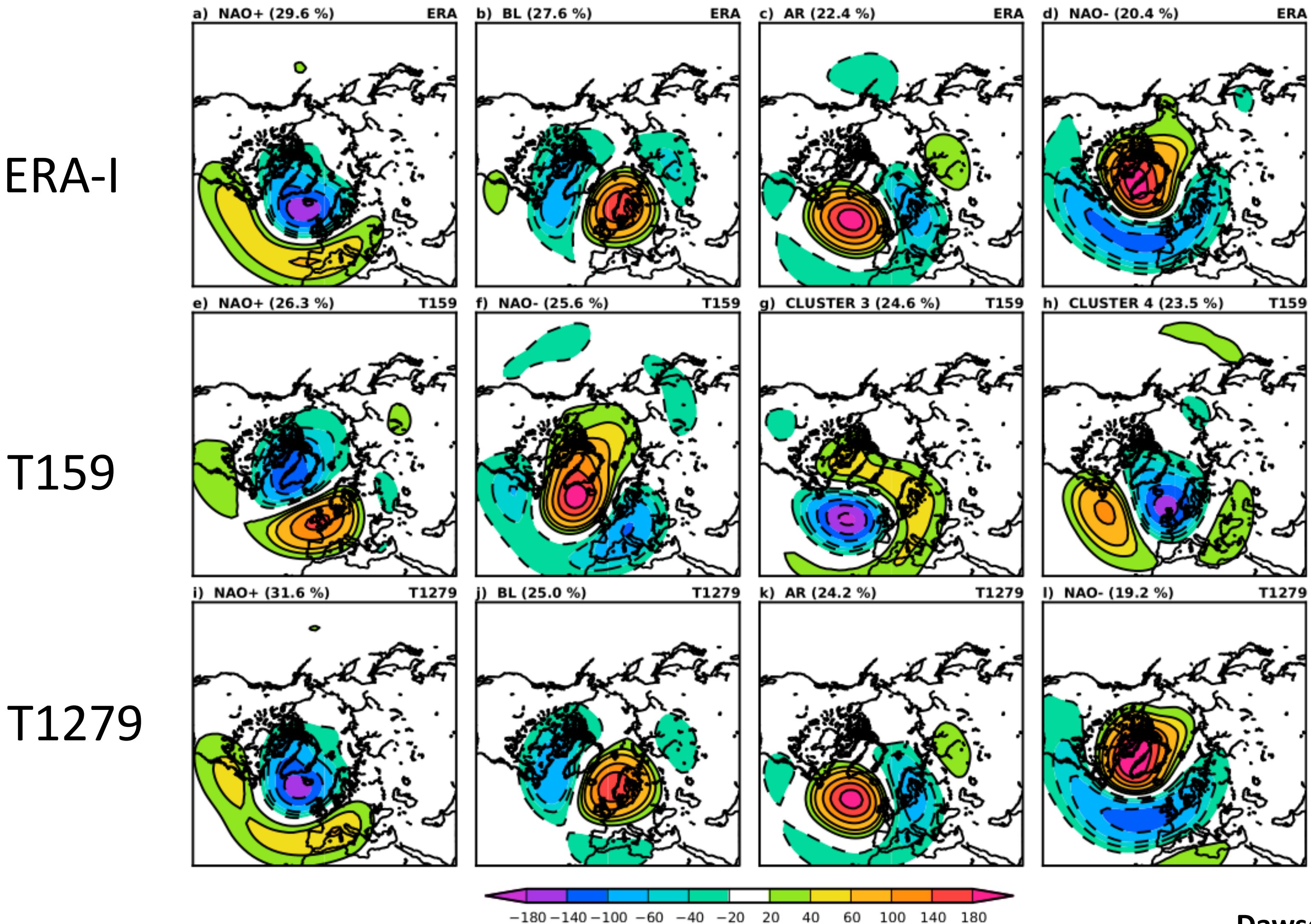
(2) ZGN < -10 m / (° latitude)

Blocking Frequencies: DJFM 1960-2007

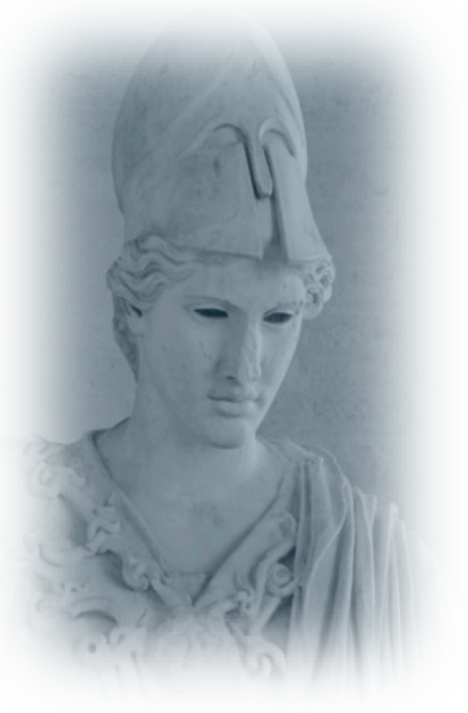


Jung et al. 2011

Regime Structures



Dawson et al. 2012



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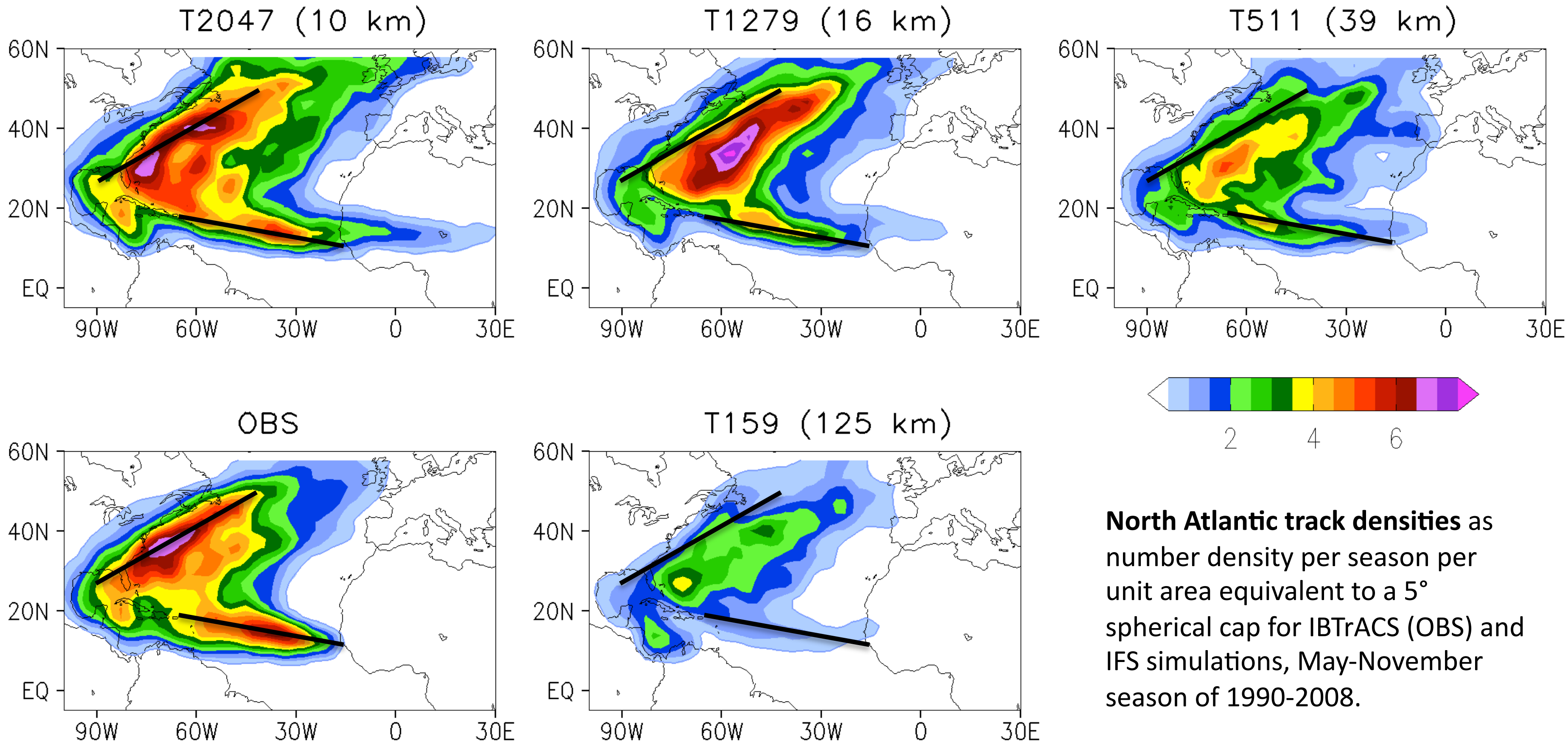


North Atlantic track densities as number density per season per unit area equivalent to a 5° spherical cap for IBTrACS (OBS) and IFS simulations, May-November season of 1990-2008.

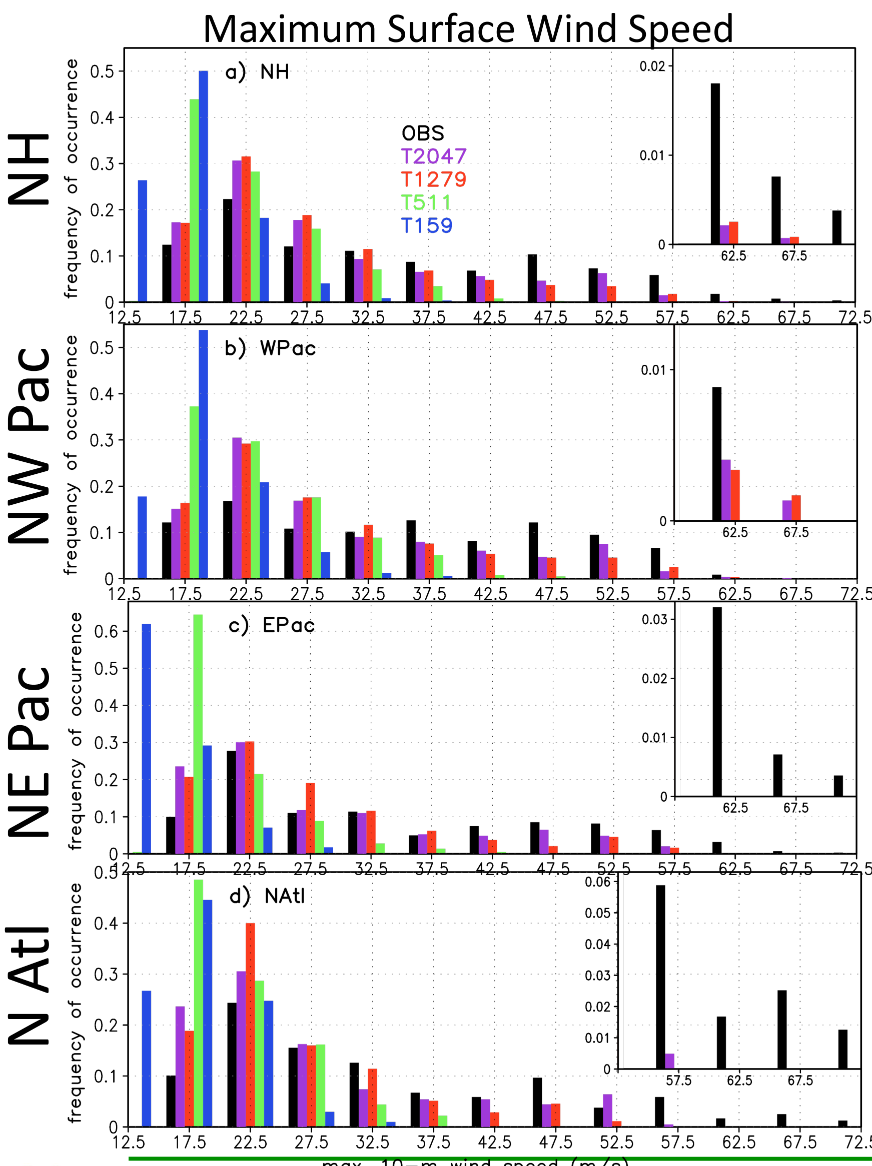
Mean TC frequency

OBS	T2047	T1279	T511	T159
12.5	10.7	**9.2**	**7.2**	**5.3**

- Units are numbers per MJJASON season.
- Model values in bold are significantly different from the OBS (at 95% confidence level).

Manganello et al. 2012

Intensity Distribution

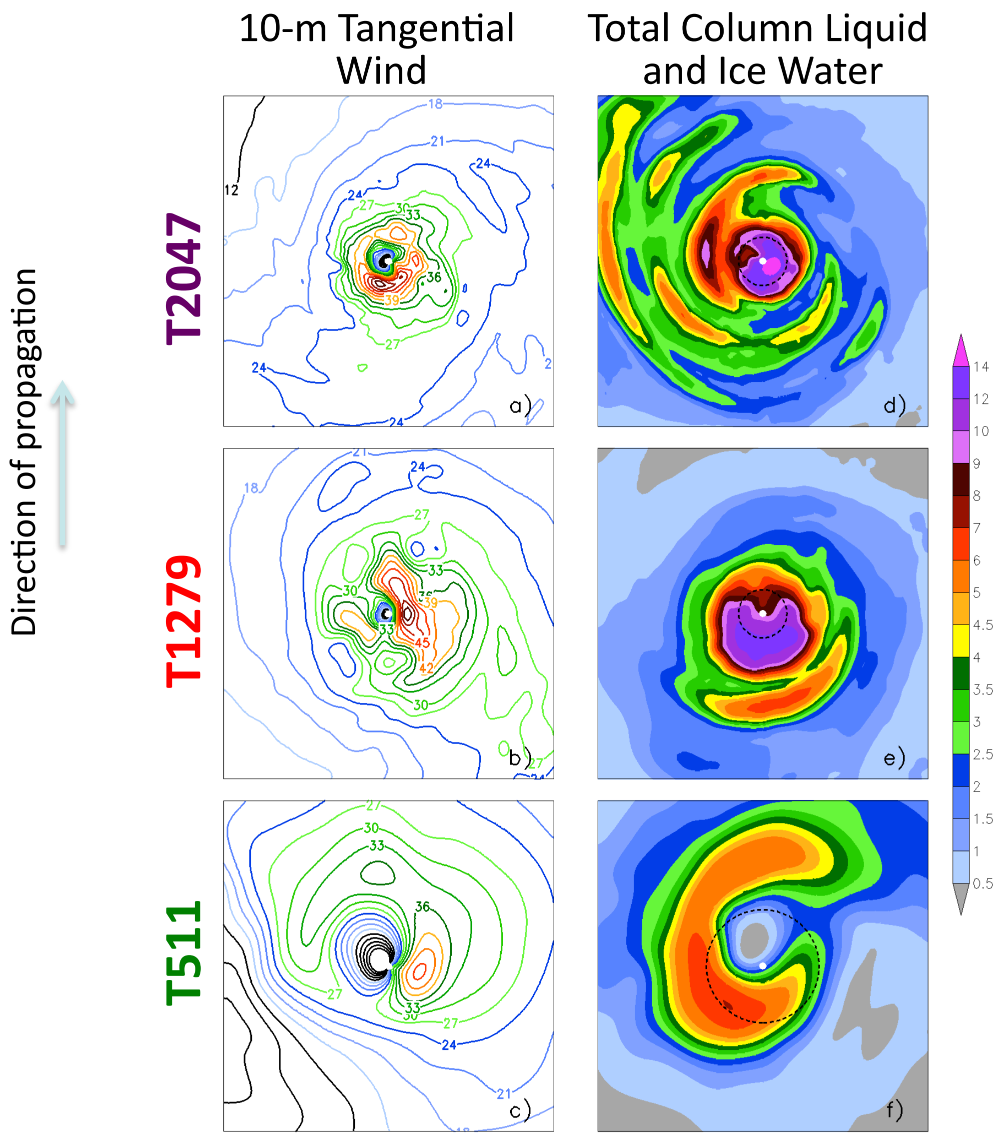


	OBS	T2047	T1279	T511	T159
Most intense TC, m/s	63.5	68.4	65.2	46.4	29.9

Most intense TC at T2047:
56.6 m/s (CAT 4)

Manganello et al. 2012

Horizontal Structure of the most intense TCs



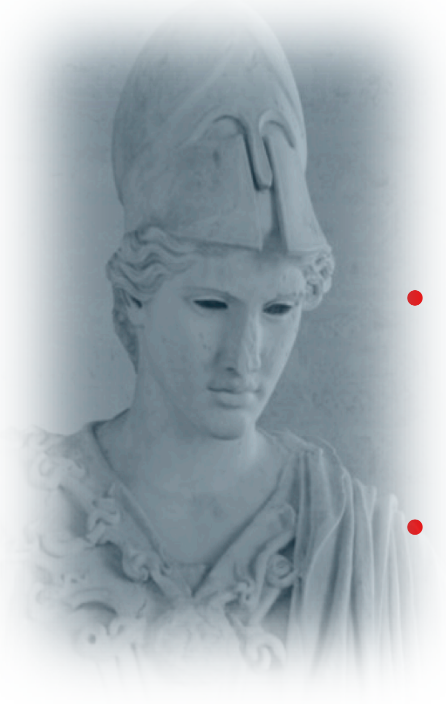
- Radius is 2° from the storm center

21^{st} Century vs. 20^{th} Century: Change in the TC Statistics for the NW Pacific

MJJASON, 47 years

	IFS T1279			IFS T159		
	TS	CAT 1-2	CAT 3-5	TS	CAT 1-2	CAT 3-5
TC Frequency, counts/year	+2.2 (+7%)			-1.1 (-4%)		
	-2.4	**+1.3**	**+3.3**	-0.8	-0.5	**+0.2**
Power Dissipation Index, $*10^{11} m^3/s^2$	**+1.8 (+51%)**			0 (0%)		
Mean Peak Intensity, m/s	**+3.4 (+12%)**			-0.1 (-0.2%)		
Mean Lifetime, hours	+0.3 (+0.1%)			+1.5 (+0.5%)		

Values in bold indicate statistically significant differences from the AMIP.



Project Athena: Summary

- **Good news:** Extreme spatial resolution **improves many of the qualitative features of large-scale climate simulation**
- **As expected:** High spatial resolution provides **higher fidelity representation of features sensitive to orography or geography**
- **Unexpected: Nonlinear dynamical effects** can alter simulation changes due to spatial resolution improvements much more and possibly in different ways than we might have expected
- **Scientific Challenge**: **Large biases remain** in hard-to-simulate fields like tropical precipitation → still need to understand and properly represent the effects of subgrid-scale physical processes

Challenges and Tensions

- Using large allocations – takes a village
- **Exaflood of data**
- Resolution vs. parameterization
- Sampling (e.g. extreme events)
- Tensions

HEC capability		**Data analysis capacity**
Automation/abstraction		**Human control**
Data-driven development		**Science-driven development**

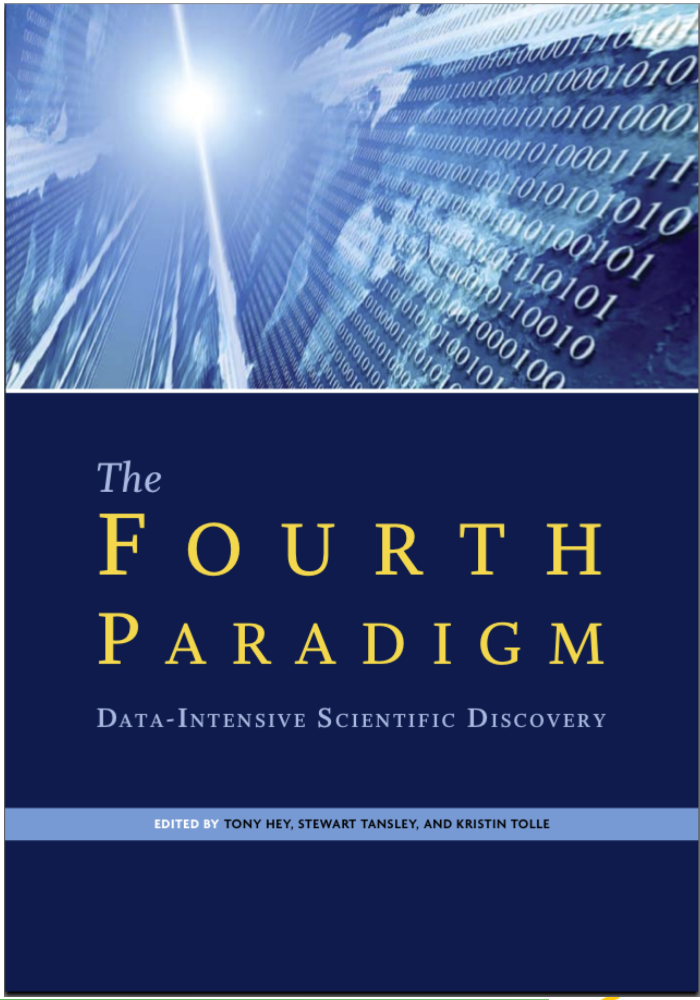
Climate scientists are being forced to think about data issues

Small, portable code		**End-to-end tools**
Tight, local control of data		**Distributed data**

Exaflood: Challenge and Opportunity

- In January 2007, Bret Swanson of the Discovery Institute coined the term ***exaflood*** for the **impending flood of exabytes** that would cause the Internet's congestive collapse.

- Hay et al., 2010: *The Fourth Paradigm* →



Athena Data Volume

- The total data volume on spinning disk at COLA for Project Athena is capped at 50 TB (for now)
- **The total data volume generated and resident at NICS is 1.2 PB (~500 TB unique)**
- That much data breaks everything: H/W, systems management policies, networks, apps S/W, tools, and shared archive space

Athena: Harbinger of the Exaflood

- Need to transform Ad hoc solutions → systematic, repeatable solutions

  (transform Noah's Ark → Shipping Industry)
- Familiar diagnostics are hard to do at very high resolution
- Have we wrung all the "science" out of the data sets, given that we have only a small percentage of the total data volume on spinning disk? **How can we tell?**
- **"We need exaflood insurance."**

  \- Jennifer Adams